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Resistance Management in Diseases of Top Fruit in Japan*

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Abstract: Top fruit is grown widely in Japan but the wet climate favours the development of diseases; this, and the demand for blemish-free fruit, necessitates the use of chemical disease control. Many applications of fungicides during the growing season could lead to the development of resistance and this paper presents a brief history, current status and future management of resistance to fungicides with special reference to diseases of apples and Japanese pears.

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1 INTRODUCTION

In Japan, top fruit is grown almost all over the country and many diseases occur due to the wet climate which favours plant pathogens. In addition, Japanese consumers require blemish-free fruit, and consequently there is a high dependence of growers on chemical disease control with fungicides applied many times during the growing season. This paper covers a brief history, the current status, and future management of fungicide resistance, mainly in apple and Japanese pear diseases.

2 APPLES

2.1 Alternaria blotch (*Alternaria alternata* (Fries) Keissler apple pathotype = *A. mali* Roberts)[1]

This is a major disease in Eastern Asia, including Japan and Korea, but it has recently become a serious summer disease also in the USA. In Japan, the antibiotic polyoxin had been widely used for Alternaria blotch control since 1968, but in 1972, strains of the pathogen resistant to polyoxin were first recorded.[2] In the orchards where highly resistant strains were present in 1978, applications of polyoxin were stopped for five years from 1979. As a result, the proportion of resistant strains rapidly declined to below 20%. However, when polyoxin was applied again, twice a year during the 1985 growing season, in combination with captan, the proportion of resistant strains tended to increase. Polyoxin remains a major component for the control of this disease but resistant strains are increasing again in fungal populations. In some cases, the field performance of polyoxin has also decreased. This antibiotic interferes with chitin biosynthesis and causes swelling of conidial germ-tubes,[3] whereas resistant conidia germinate normally. Spore germination tests can, therefore, be used to distinguish resistant from sensitive isolates.

In orchards where iprodione had been applied more than 20 times in total, control efficacy of this fungicide started to decline, and in 1978 iprodione-resistant strains were detected (Hiraragi & Nakano, unpublished). Monitoring results indicated that the resistant strains were probably less fit than sensitive ones in the absence of iprodione (Asari & Takahashi, unpublished). To avoid any increase of resistant strains, an anti-resistance strategy is recommended as follows:

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polyoxin or iprodione in a mixture with oxine copper-captan; fosetyl-captan mixture and the alternate spraying of captan and other fungicides containing polyoxin or iprodione. The multi-site-inhibiting fungicide captan is particularly important for the control of summer diseases and as a partner fungicide in mixed applications. It is generally accepted that risk of resistance to captan, if any is low. A few cases of captan resistance have been reported so far, but only in *Botrytis cinerea* Pers. ex Fr.,[4] where the impact of resistant strains on control efficacy has remained unclear. A decrease of field performance of captan against Alternaria blotch has been reported frequently in Japan, although an involvement of resistance has not been well demonstrated in laboratory tests.[5]

Registration of two broad-spectrum strobilurin fungicides, azoxystrobin and kresoxim-methyl is under way in Japan, and we are trying to establish in-vitro testing methods for strobilurin sensitivity. However, inhibitory effects of azoxystrobin on conidial germination of *A. alternata* are not so strong as those of conventional respiration inhibitors (Ishii *et al.*, unpublished).

2.2 Scab (*Venturia inaequalis* (Cooke) Wint.)[6]

Experiments for the simultaneous control of scab, powdery mildew, etc. were conducted in an experimental orchard in Hokkaido. However, in 1972, the third year of the use of benzimidazoles, failure of scab control was recognized,[7] and this was confirmed to be caused by the development of benzimidazole-resistant strains of *V. inaequalis*.[8] Subsequently, benzimidazole fungicides have been withdrawn as scab control agents, although thiophanate-methyl is often used for the control of canker caused by *Valsa ceratosperma* (Tode ex Fries) Maire.

Sterol demethylation inhibitors (DMIs) are most important for scab control. Immediately after registration of DMIs, application of these fungicides was strictly limited to two or three times per year to avoid the practical problem of resistance. In the spray calendar for apple diseases and pests published by Aomori Prefecture, 1997, application times of DMIs are limited to three out of 13 total applications. They recommend the use of DMIs as a single application just before blossom, followed by two mixed applications. Many reports are now available on DMI resistance in apple scab worldwide,[9] but in Japan, neither loss of field efficacy of DMIs nor detection of resistant strains has been experienced so far. Monitoring DMI sensitivity of *V. inaequalis* is being carried out regularly.

The anilinopyrimidine fungicide mepanipyrim has been registered for the control of scab, Alternaria blotch, fruit spot, etc. and a tank mixture of mepanipyrim with ziram and thiram is recommended. Strobilurins have been submitted for registration and are planned to be used as a single application for the simultaneous control of main diseases in summer (Fujita, pers. commun.). Methods for assessing sensitivity to these new fungicides and establishing the baseline sensitivity are being developed. In *V. inaequalis*, MIC values *in vitro* of azoxystrobin based on mycelial growth on potato dextrose agar plates varied widely, but EC_{50} values were below 1 mg litre^{-1} for most isolates tested (Ishii *et al.*, unpublished).

3 JAPANESE PEAR (*Pyrus pyrifolia* Nakai var. *culta* Nakai)

3.1 Black spot (*Alternaria alternata* Japanese pear pathotype = *A. kikuchiana* Tanaka)

In 1971, the sudden appearance of black spot, regardless of successive treatments with polyoxin, was reported in Tottori Prefecture.[10] The results from extensive work clearly indicated the emergence of polyoxin-resistant strains in these natural populations. In the orchards where control efficacy of polyoxin declined, other unrelated fungicides were used instead and annual changes of the frequency distribution of resistant strains were subsequently monitored in the field.[11] When the use of polyoxin was discontinued, highly resistant strains dominated the fungal populations, and no intermediately resistant strains were detected at that time in any of the orchards examined. The highly resistant strains declined year by year, and by the tenth year after the withdrawal of polyoxin, such strains resistant to this material were undetectable. In contrast, the rates of occurrence of intermediately resistant strains, and, to a lesser extent, of sensitive ones increased slowly.

Some years later, it was suspected that emergence of iprodione-resistant strains played a role in poor disease control with this fungicide.[12] Recently, the black-spot-tolerant pear cultivar ‘Gold Nijisseiki’ was obtained by irradiation breeding and has been released to pear growers.[13] It is expected that introduction of this new pear cultivar will halve both the frequency of fungicide applications and the risk of fungicide resistance, as the integrated use of disease-resistant cultivars together with fungicides will reduce selection for fungicide-resistant strains of the pathogen.

3.2 Scab (*Venturia nashicola* Tanaka & Yamamoto)

Benzimidazole fungicides had been used extensively since 1971 for the control of scab, and efficient control was achieved initially. In 1975, however, spray applications of benzimidazoles failed to control scab.[14] Benzimidazole-resistant strains still constitute a high proportion of the population despite the fact that the use of benzimidazoles was stopped in many orchards.[15]

DMIs have become a major group of fungicides since the mid-1980s, when benzimidazoles lost their efficacy

in most areas. Public sector organisations like Prefectural Research Stations or the extension service, generally advise growers to use DMIs around three times a year in mixture with other fungicides with a different mode of action. Nevertheless, growers tend to apply DMIs more frequently than recommended in the spray calendar. These days, growers occasionally complain about the field performance of DMIs, although no signs of resistance have been detected from oridinary monitoring studies.

At first, baseline sensitivity data on fenarimol were obtained using fungal isolates which were collected from non-DMI-treated trees in Japan and even in China.[16] In these two cases, mean EC_{50} values of fenarimol for mycelial growth were 0·199 and 0·12 mg $litre^{-1}$, respectively. Monitoring of fenarimol sensitivity in 1992 through 1994 revealed a shift to lower fenarimol sensitivity in many strains isolated from DMI-treated pear orchards. To examine whether efficacy of fenarimol had also declined, spore samples were collected from commercial orchards from which less fenarimol-sensitive strains had been found in tests *in vitro*. However, in inoculation tests on pear seedlings, fenarimol still showed adequate control, indicating that the performance of fenarimol was still maintained in the field.

I will briefly mention some of the difficulties experienced in monitoring DMI sensitivity in *Venturia* species. Mycelial growth in *Venturia* spp. is very slow and we often experienced a decrease in the level of DMI resistance when we stored and/or subcultured pure isolates of *V. inaequalis* and *V. nashicola*.[17] Therefore, it is doubtful whether our monitoring studies reflected the real situation of the DMI sensitivity of the fungal populations from the field. The long time required for confirmation of fungicide resistance interferes with quick and accurate decision-making to minimize the control failure with the fungicides. It is definitely necessary to develop more rapid and simpler methods for testing DMI sensitivity with this pathogen. In DMI-sensitive conidia of *V. nashicola*, thickening and swelling of germ-tubes are frequently observed under the microscope in the presence of DMIs,[18] but, this method has not yet been used in practice.

4 ACTIVITIES OF THE RESEARCH COMMITTEE FOR FUNGICIDE RESISTANCE AND OTHERS

This Research Committee was founded in 1991 and it is now one of the committees authorized and sponsored by the Phytopathological Society of Japan. A symposium is held regularly on the day following the annual meeting of the Society. Manuals for testing fungicide and bactericide sensitivity of major pathogens have been compiled and will be published in 1997. They will also cover almost all bibliographies on fungicide and bactericide resistance which have been reported within Japan since 1971.

Based on the agreement between British and Japanese governments, an International Workshop on Fungicide Resistance was held in Tsukuba, Japan in 1995, and several references in this paper are from the Proceedings of that workshop.[19]

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